

THIN FILM SOLAR CELL WORKSHOP

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The following is a summation of responses to questions posed to the thin-film workshop and the ensuing discussion. Participants in the workshop included PV manufacturers (both thin film and crystalline), cell performance investigators, and consumers (spacecraft designers, program managers).

(1) Will Amorphous Silicon (a-Si) Ever Be Stable?

Maybe. In the worst-case scenario, long term efficiency will stabilize 10% below annealed efficiency. But the more relevant question is: what will be the end of life (EOL) efficiency for a typical mission? Presently, the highest stabilized efficiency for a 1 ft² module is 8.5%. Based on studies from JPL and Wayne State, combination of radiation created defects and annealing at operating temperature will cause typical EOL efficiencies slightly lower than this. An end of life array efficiency of 8% might be expected with current a-Si technology.

(2) What is Required to Establish Use of Thin-Film Cells in Space?

As is the case with any new photovoltaic technology, a full battery of standard space qualification testing on a given cell design must be conducted. In addition, flexible thin-film devices must also be subjected to extensive mechanical and thermal cycling testing. Ultimately, it is important that spacecraft designers be confident in the thin-film technologies. Thus, flight experience must be gained to establish a heritage with these devices before serious consideration is given to thin-film solar cells and modules.

However, other considerations must be given to thin-film technologies. Unlike conventional crystalline devices, thin-film PV technologies are strongly linked to an accompanying array design to utilize their properties fully. This is particularly the case with flexible devices which usually are linked with novel array designs. For this reason, it may be necessary to qualify the thin-film PV technology with an associated array design.

Finally, as was the case with the introduction of gallium-arsenide (GaAs), use of thin-film devices may not occur until a given application absolutely requires it due to its combination of low installed cost, high specific power, and improved radiation resistance when compared to conventional crystalline technology.

(3) What Thin-Film Cells Can Be Put on Lightweight Substrates? Key Technical Barriers? Status?

All of the thin-film cells, including a-Si, copper-indium-diselenide (CIS), and cadmium-telluride (CdTe) can be deposited onto lightweight substrates. Selection of substrates for most of the devices is limited by processing temperature and processing environments which may damage the substrate. Furthermore, some surface texture may also be detrimental to device fabrication.

Amorphous silicon has been demonstrated on both metal foils and polyimide substrates. Fully-integrated, large-area modules have been demonstrated on polyimides. CIS solar cells have been manufactured onto metal foils (aluminum, titanium, molybdenum), while large-area modules have been demonstrated on glass substrates. Until recently, lightweight CdTe has not been manufactured for space applications because of its superstrate structure. Now, lightweight CdTe cells have been manufactured on polyimides.

(4) What are Realistic Cost Goals, Given Space Market Volume?

The general consensus is that thin-film PV can have significant impact on cost, particularly due to monolithic integration and its associated reduced installed labor and reporting cost. Some calculations indicate that a 1

ft² module can result in an 80% installed cost reduction, even on a limited space volume. It would be particularly helpful if a thin-film space PV program can "piggyback" onto an existing terrestrial program for a larger production volume.

A minimum order will be required to make it attractive for manufacturers to make the effort for a space-based device. Such an order may be on the order of \$10,000 to \$100,000, depending upon the type of qualification and the deviation from standard processing required.

(5) Potential Space Applications?

Because the devices exhibit the important qualities of high specific end-of-life power and low cost, they can be used in most applications. In particular, missions such as orbit transfer vehicles which dwell for a significant time in radiation-rich environments are ideally suited for thin-film PV. Furthermore, any surface-based (lunar, martian) power stations which require low mass will also be ideal for these technologies.

Quite possibly, the only missions for which thin-film PV might not apply are array area critical missions, such as low earth orbit where array drag is critical in station-keeping requirements. Attempts at array size reduction, at present, is inhibited by lower device efficiency, although technologies such as CdTe have been demonstrated at efficiencies above 16%.

(6) Are Tandem Thin-Film Cells Practical?

Tandem cells for a-Si are required for the 10% stability noted above. Because of the continuous in-line processing used for thin-film devices, the addition of another device is not as cost-prohibitive as compared to crystalline technologies.

CIS has been used in a tandem cell configuration as well, and it is possible to manufacture a CIS/CdTe tandem cell. As is the case with a-Si, it is possible to make a cost-effective process which can manufacture such devices.

(7) Are Space-Qualified Encapsulants Needed? Are They Available?

At present, data are not yet available on the requirements of thin-film device encapsulants. Furthermore, flexible devices cannot use conventional cover glass technology used with crystalline devices. Because polymers are affected by atomic oxygen and radiation, conventional thin-film encapsulants probably cannot be used for orbital use. Some fluoropolymer encapsulants may be usable on surface power missions.

(8) Is There a Required Minimum Efficiency?

Quite probably, this question is the most difficult to answer. Spacecraft designers in the workshop indicated that efficiencies comparable to silicon, which is most commonly used in space, would warrant immediate use of thin-film devices. However, the high specific power, low stowage volume, low cost, and radiation damage resistance may drive this efficiency requirement much lower than the typical 14.5% Si efficiency. An efficiency of 9% end-of-life with the crystalline thin-film technologies may be a guideline.